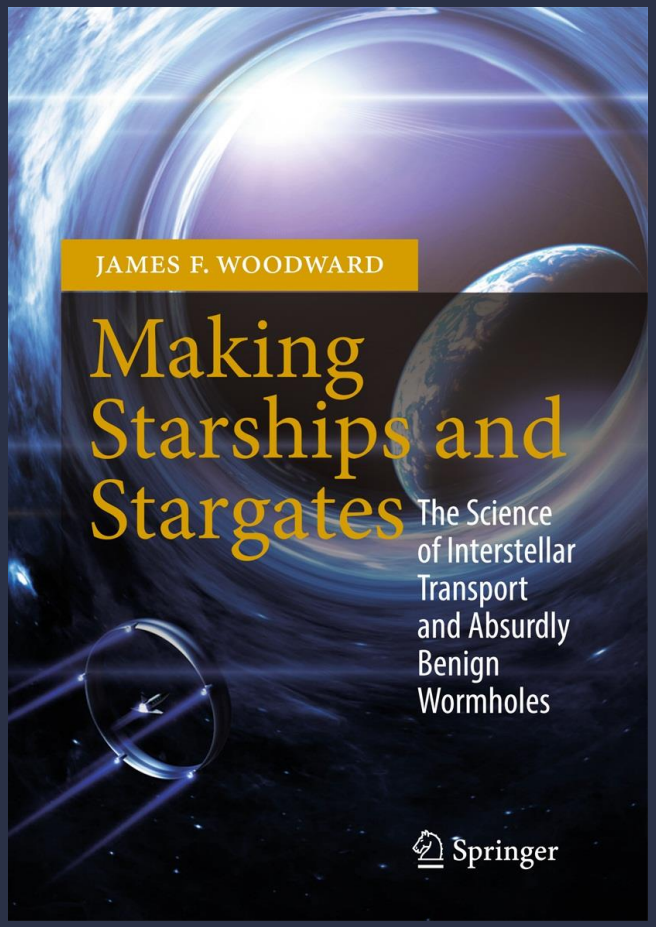
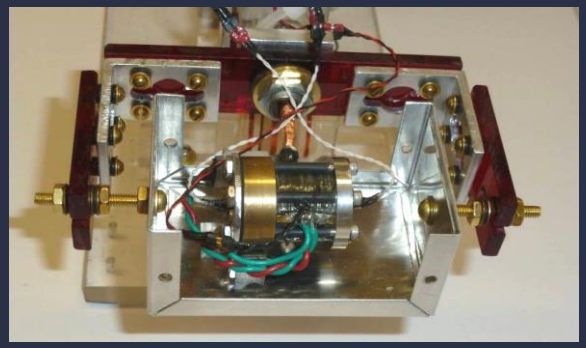
Theory & Experimental Work on Mach Effect Thrusters (MET)



Professor Heidi Fearn
and J. F. Woodward
Cal State, Fullerton



Talk Overview:

- Theory of the Mach effect drive, Mach effect? Advanced waves?
- How does it work?
- Experimental results and new directions.

Mach's Principle:

A body's inertial mass is determined by the universe's mass-energy distribution.

Ernest Mach rejected the existence of absolute space, in favor of relative motion with respect to a "fixed frame," provided by the matter distribution in the universe.

Higgs particle?? W and Z bosons only.
The majority of mass for the p and n comes from k.e. of quarks and gluons not sum of their tiny masses.

Books with Mach Principle Definitions

Quantum Gravity by Carlo Rovelli… 8 different definitions
Mach's Principle from Newton's Bucket to Quantum Gravity
Birkhauser Press.. Also Bondi and Samuel arXiv:gr-qc/9607009 (1996)

Mach 1: Distant stars can affect the LIF (local inertial frame) … true

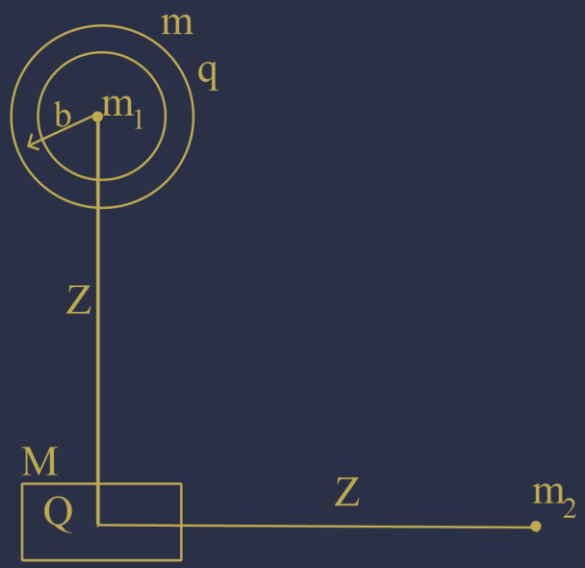
Mach 3: The rotation of the LIF inside the bucket is dragged by the bucket… true.. Lens-Thirring effect is Machian.

Mach 7: There is no absolute motion only motion rel to something else… true.. Basic physical idea of GR

Mach 8: The LIF is completely determined by the dynamical Fields in the Universe… true

Particle inside an Accelerating Mass shell (by Einstein 1912 and Lynden-Bell 1995)

Strong support for Machian Ideas. Einstein was very much influenced by Mach.
Rotational form known as frame dragging..



Advanced and Retarded waves

Dirac radiation reaction… 1938

Proc. Roy. Soc. Lon. (PRSL) A167, 148 (1938)

Wheeler Feynman Absorber Theory.. 1945 RMP.

John Cramer's Transactional QM.. 1986 RMP.

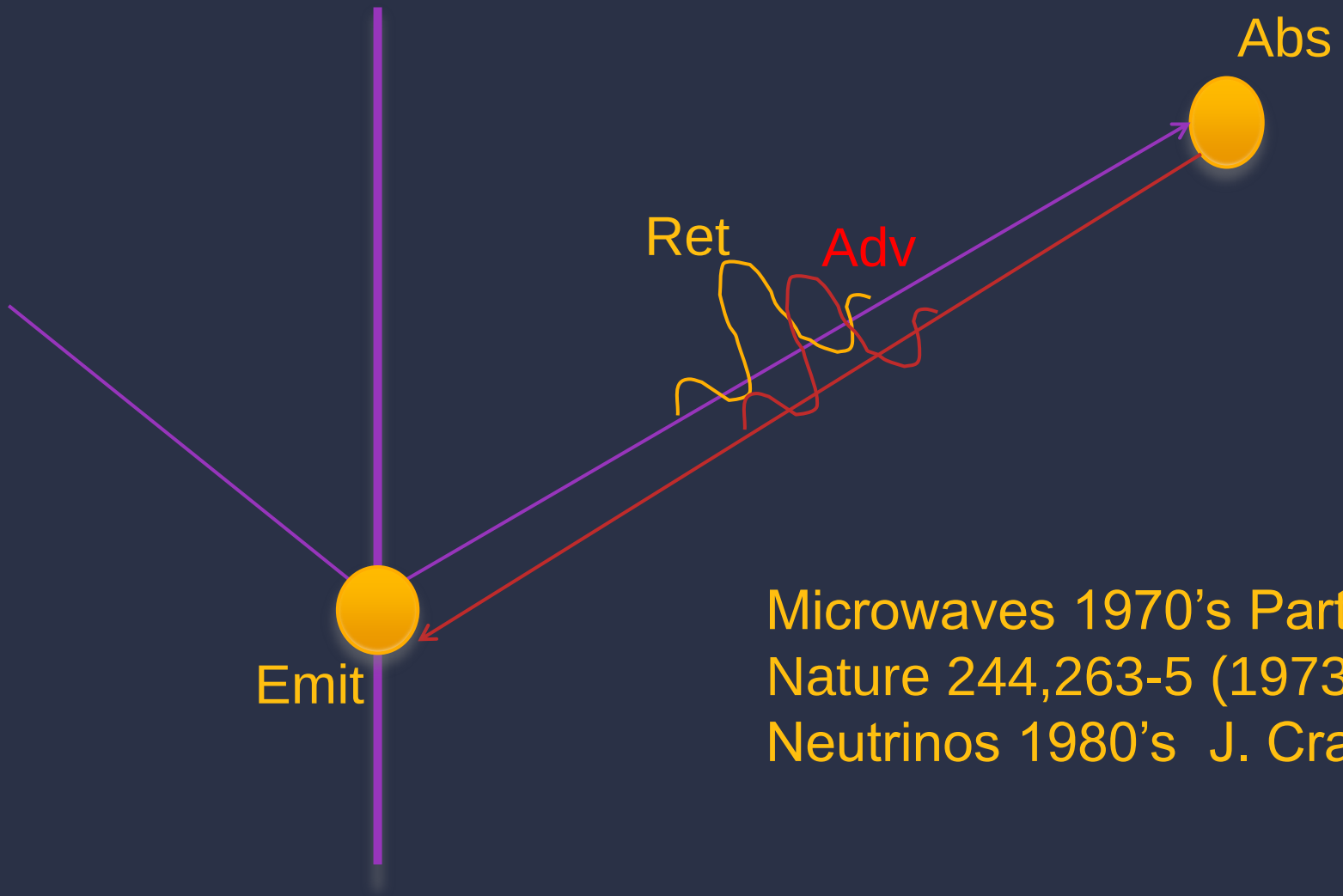
Hogarth.. PRSL A267, 365 (1962) … arrow of time related to universe expansion not thermodynamics.

Hoyl and Narlikar PRSL A282, 191 (1964). A new theory of gravitation , new eqn of motion, not exactly the geodesic, with mass change terms! Fully Machian. Reduces to Einstein's theory in the limit of particle distribution as a smooth fluid. Needs some work to pull it up-to-date! In progress.

Advanced wave Signaling? Interstellar- time dilation problems?

Microwaves 1970's Partridge Nature 244,263-5 (1973).
Neutrinos 1980's J. Cramer

Advanced waves…



Microwaves 1970's Partridge
Nature 244,263-5 (1973).
Neutrinos 1980's J. Cramer

Woodward's "MACH EFFECT" EQN

QUANTIFIES THE MAGNITUDE OF THE PREDICTED MASS FLUCTUATIONS IN ACCELERATED OBJECTS:

$$\delta m_0 \approx \frac{1}{4\pi G}\left[\frac{1}{\rho_0 c^2}\frac{\partial P}{\partial t} - \left(\frac{1}{\rho_0 c^2}\right)^2 \frac{P^2}{V}\right]$$

- The linear term in *P* [the power delivered to a capacitor] is the "impulse engine" term.
- The quadratic term in *P* is the "wormhole" term (because it is always negative), normally a factor of $1/c^2$ smaller than the impulse engine term.
- Note, however, that this is only true for extended objects under-going "bulk" accelerations.

Jim Woodward's mass fluctuation equation

$$\nabla^2 f - \frac{1}{c^2}\frac{\partial^2 f}{\partial t^2} = 4\pi G\rho + \left[-\frac{1}{m^2}\left(\frac{\partial m}{\partial t}\right)^2 + \frac{1}{m}\frac{\partial^2 m}{\partial t^2} \right]$$

Note the transient terms on the RHS of the eqn.

Woodward: These eqns need work!

The Mach effect mass fluctuation written with explicit acceleration dependence:

$$\delta m_0 \approx \frac{1}{4\pi G \rho_0 c^2} \frac{\partial P}{\partial t} \approx \frac{1}{4\pi G \rho_0 c^2} m_0 a^2$$

At resonance the time average gives

$$V = V_0 \cos wt$$

$$\mathbf{F} = d m_0 \ddot{x} \gg \frac{w^6 m_0 K_p^2 K_e x_0^3 V_0^4}{8 p G r_0 c^2}$$

Very basic..
Needs work and
Real modeling.

(The calculation is in Woodward's book and previous papers)

Hoyle & Narlikar (Fully Machian)

New eqn of motion replacing geodesic (c=1)

$$\frac{d}{da}\left(m_a \frac{da^a}{da}\right) + m_a G^a_{bg} \frac{da^b}{da}\frac{da^g}{da} - g^{ab}\frac{\partial m_a}{\partial a^b} = e_a \sum_{a \neq b} F_b^{(b)a} \frac{da^b}{da}$$

Smooth fluid approx gives, rest frame gives back Einstein's eqns.

$$\frac{1}{2}m^2\left(R_{ab} - \frac{1}{2}g_{ab}R\right) = -3T_{ab} + m(g_{ab}g^{mn}m_{;mn} - m_{;ab}) + 2(m_{;a}m_{;b} - \frac{1}{4}m_{;g}m^{;g}g_{ab})$$

In flat spacetime $g_{ab} \to h_{ab} = diag(-1,1,1,1)$ divide by $m^2/2$

$$-\frac{4}{m}\left(\frac{\partial^2 m}{\partial t^2}\right) + \frac{3}{m^2}\left(\frac{\partial m}{\partial t}\right)^2$$

The gravitational/inertial effects in question are transients;

fluctuations in the rest-masses of objects accelerated by external forces that undergo changes in their internal energies as they are accelerated.

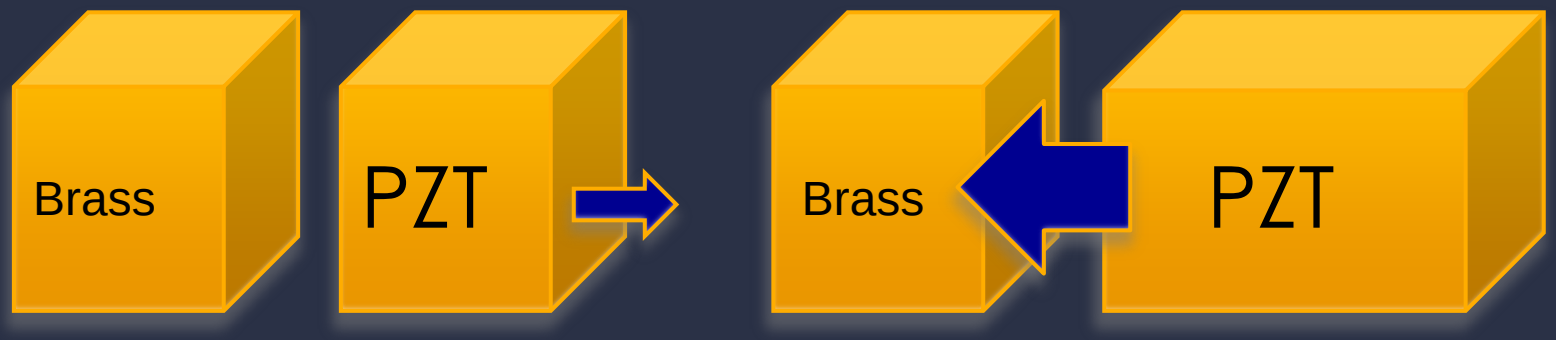
PZT IS THE ACTIVE MASS, (PIEZO-ELECTRIC EFFECT … V)

THE EXTERNAL FORCE IS CAUSED BY THE ELECTRO-STRICTIVE FORCE IN PZT, GOES AS V^2

How do METs work?

- METs depend on "Mach's principle" being correct.
- Mach's principle is the proposition that all inertial forces – the forces of reaction in Newton's third law of mechanics – are produced by the gravitational action of all of the "matter" (everything that gravitates) in the universe.
- In our universe, the conditions needed for this to be true in general relativity are those in fact observed – spatial flatness at cosmic scale.
- When the action of gravity on accelerating local objects is analyzed in relativistically correct fashion, it is found that the rest masses of accelerating objects that are also changing their internal energies (being squished) change. They fluctuate.
- If these rest mass fluctuations are produced periodically, and a second periodic force is brought to bear, you can push heavy, pull light on the fluctuating mass and produce a steady thrust.

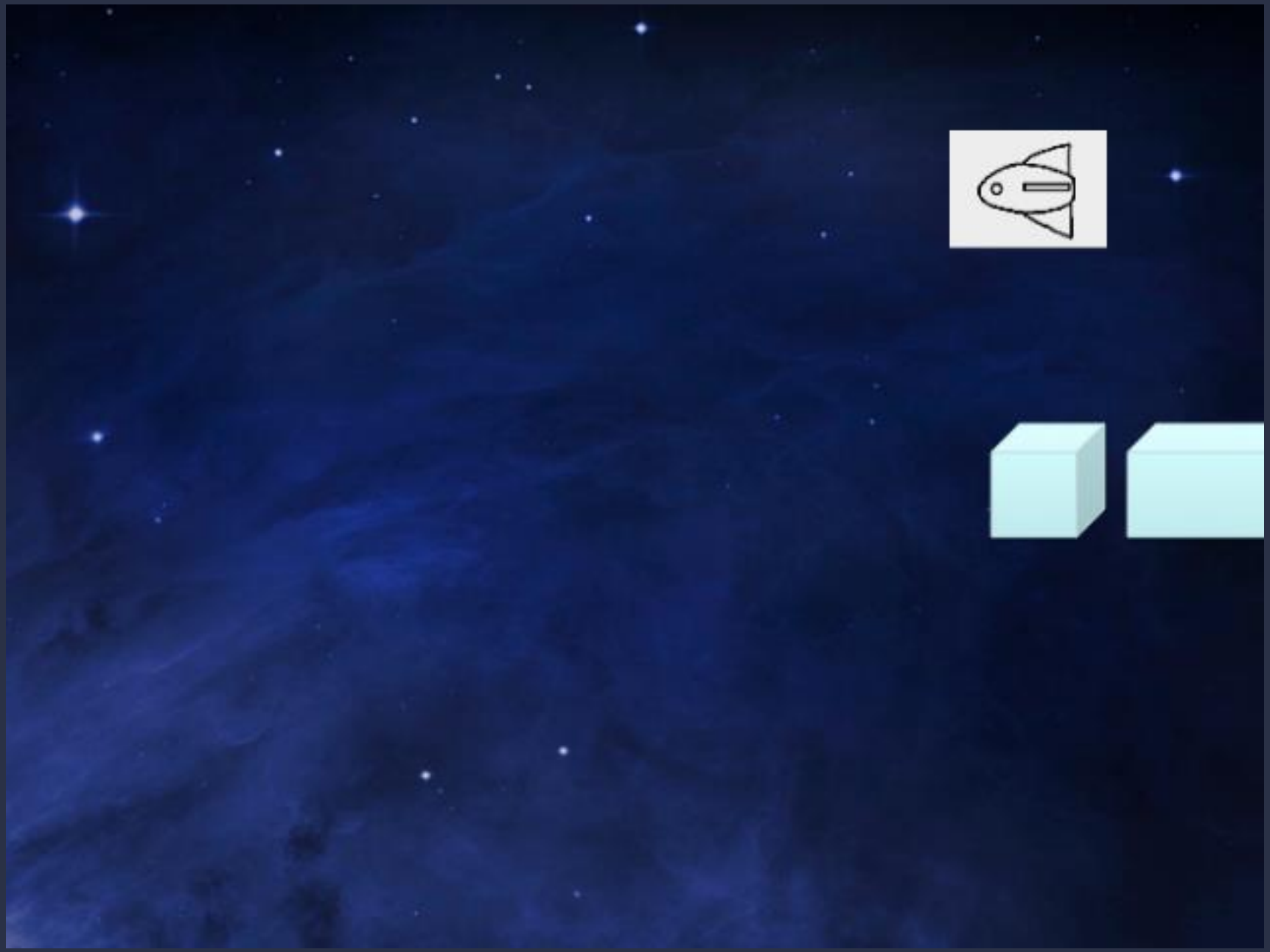
What if you can make the mass of a PZT disc fluctuate, and act on it in a direction when it is heavier and in the opposite direction when it is lighter?

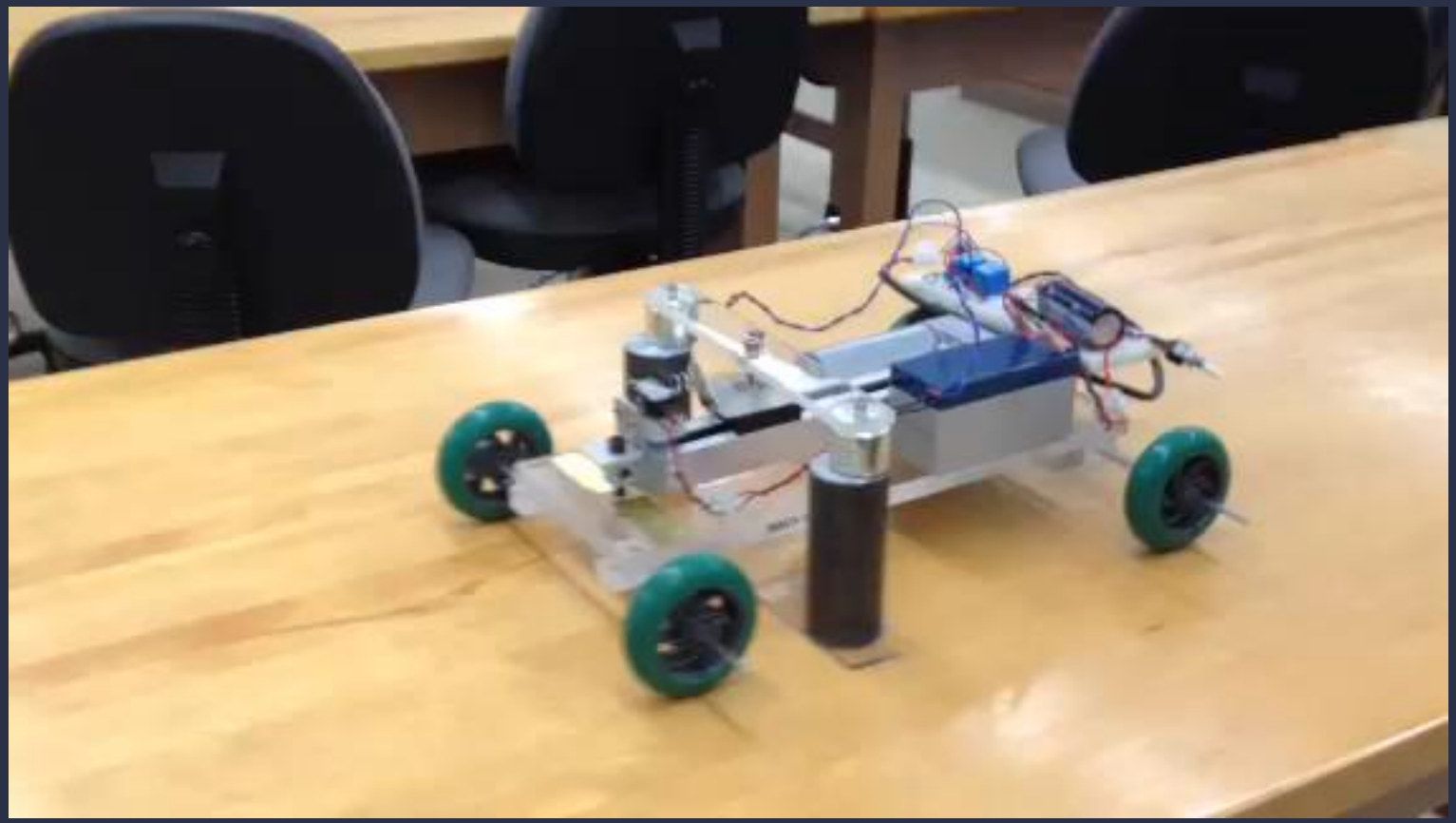


Pull on reaction mass when light.

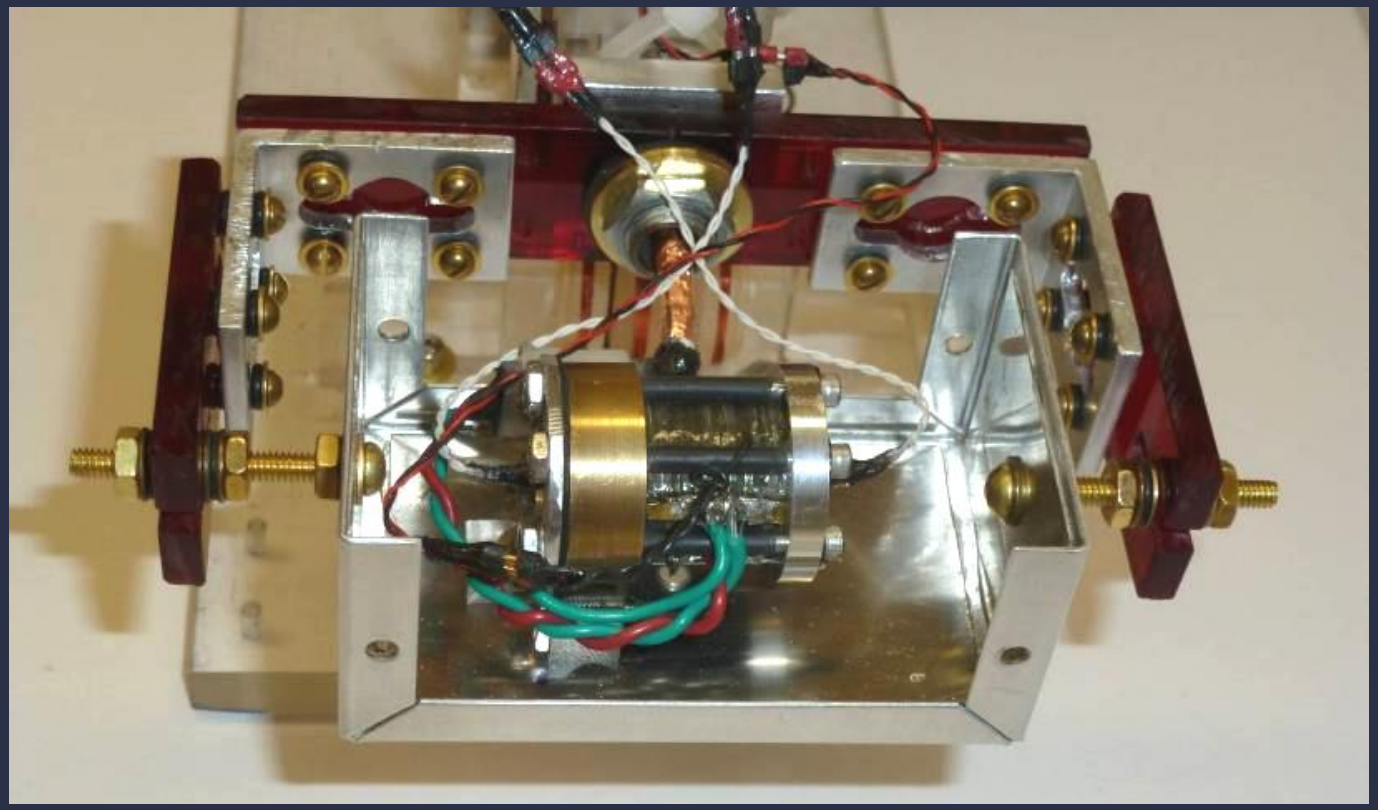
Heavy, push : PZT expanding

ACCELERATION

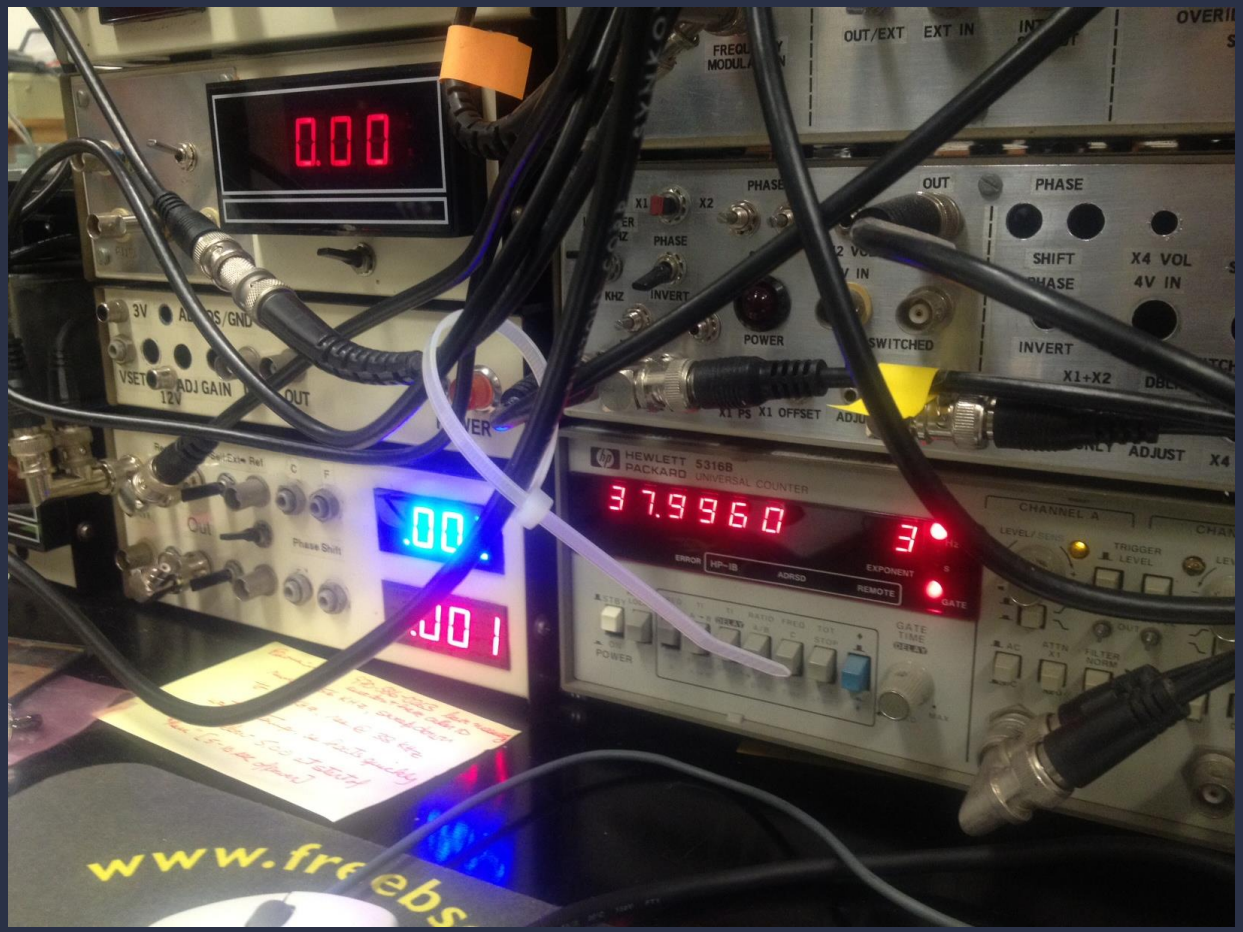


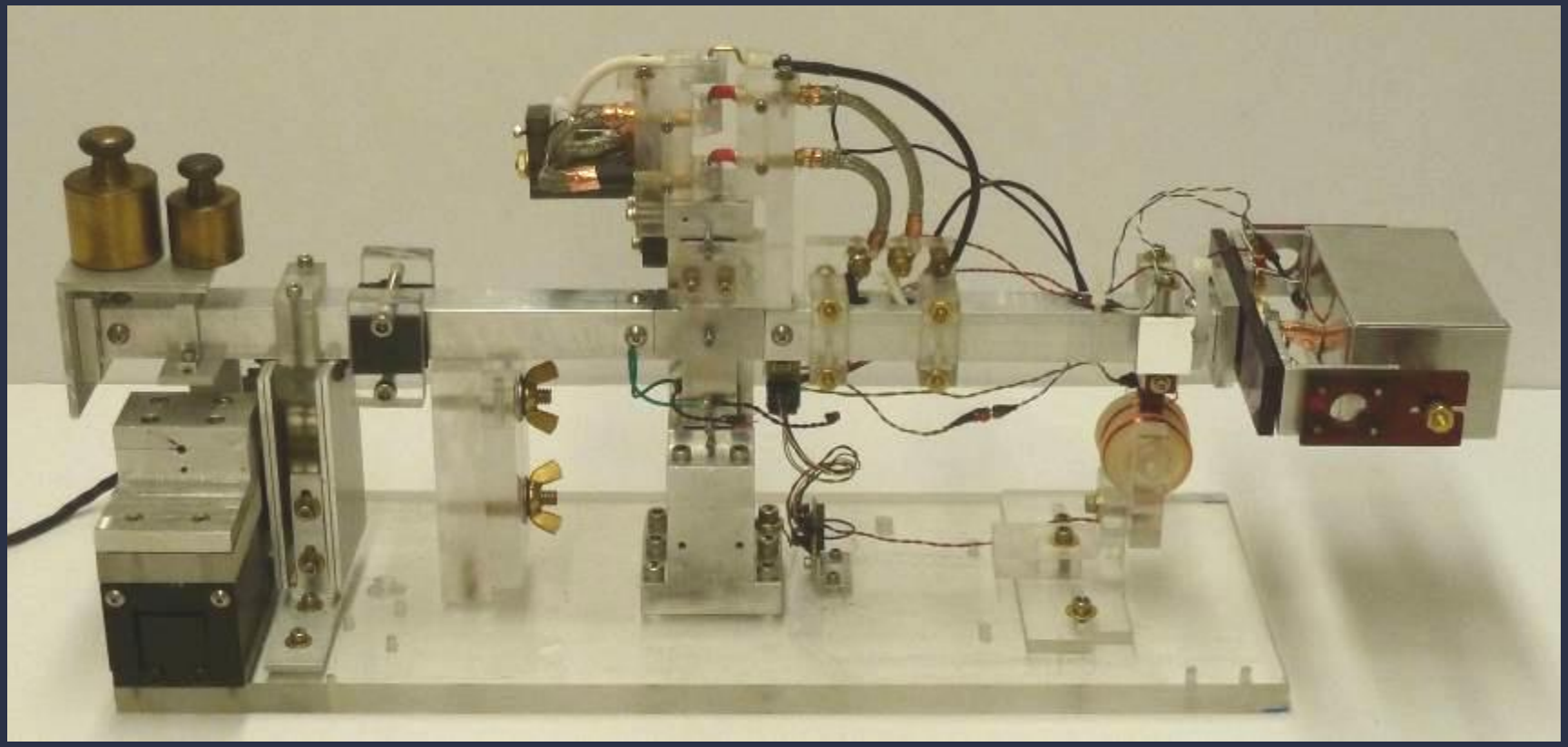


Devices to test for the presence of Mach effects



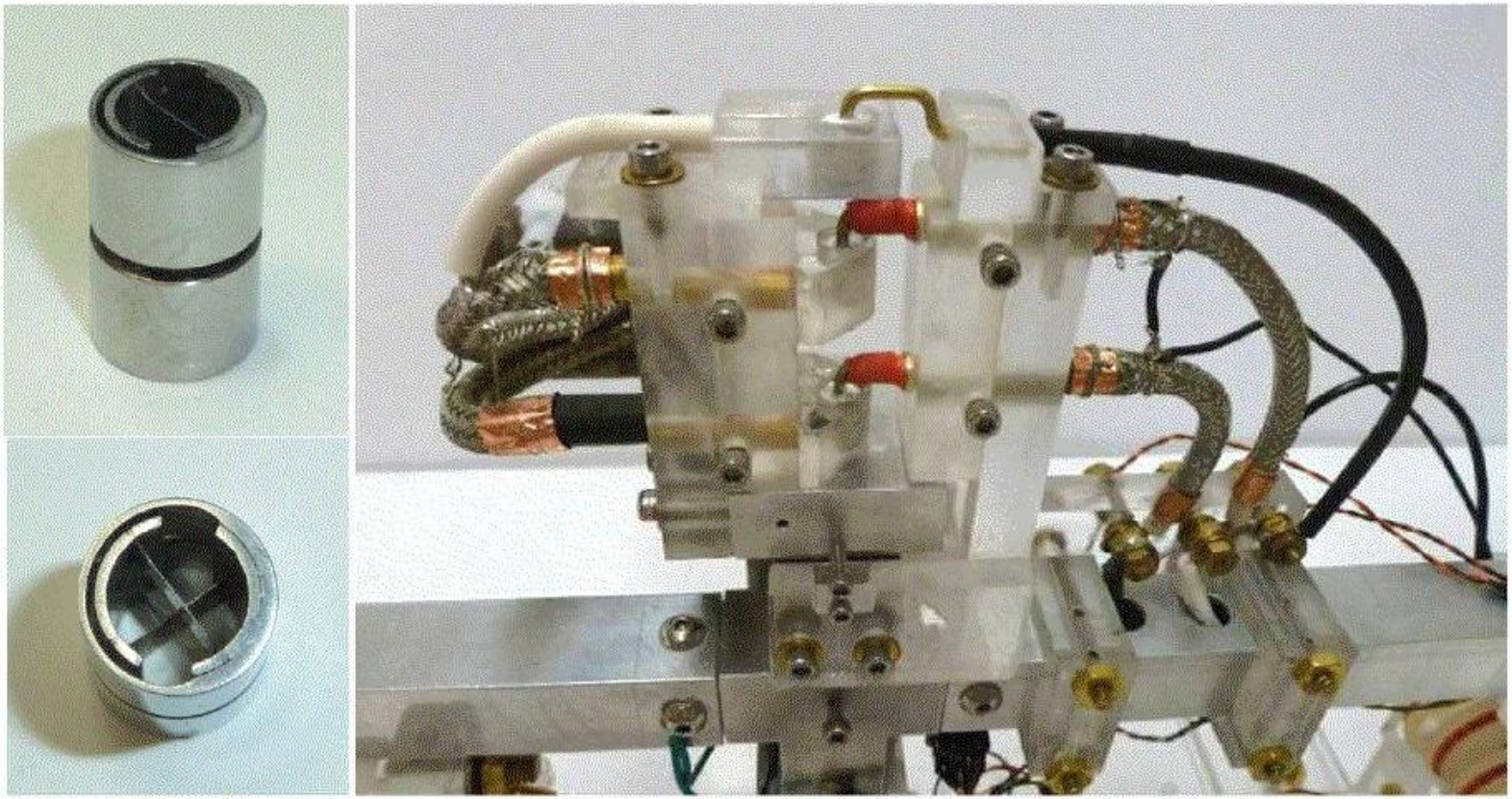
Experimental Protocols & results, new directions.





USC/ARC Style Thrust Balance:

- A Faraday cage (mounted on right) holds the test device.
- Flexural bearings in the center column support the beam.
- A Philtech optical position sensor measures beam displacement.
- Wire coils (below & left of Faraday cage) calibrate the thrust sensor.



Detail of Thrust Balance Central Column:

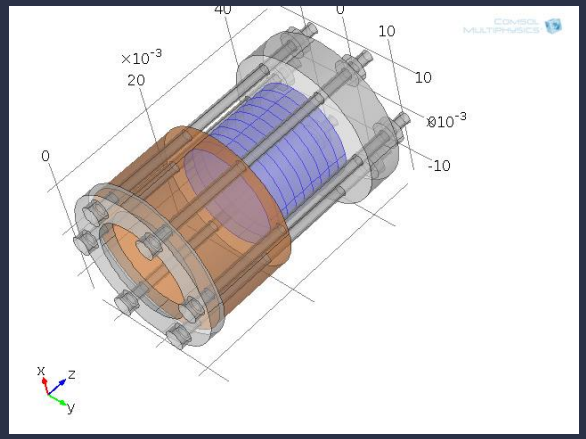
- Left: C-Flex, E-10 flexural bearings support the main beam.
- Right: Liquid metal contacts provide power to on-beam systems.

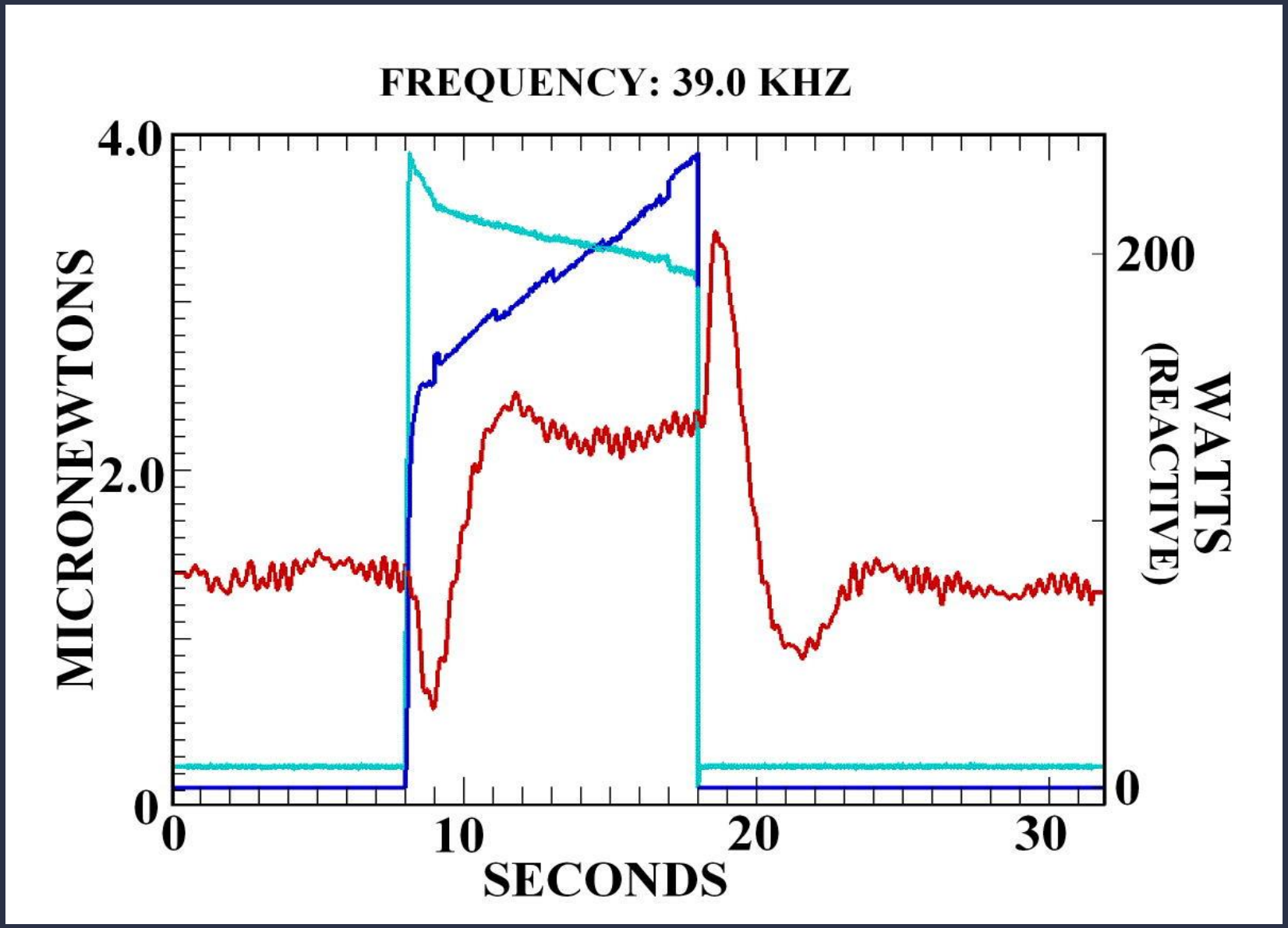
Experimental Protocol

- Devices only produce observable thrust when the driving signal's frequency is on a resonance, specific to each device.
- Standard data acquisition runs consist of five stages:
  - A brief period of no applied power to measure spurious noise.
  - A pulse of on-resonance power
  - A sweep of the frequencies above and below the resonance
  - Another on-resonance pulse
  - A final period of no applied power
- We monitored several variables:
  - Thrust
  - Voltage across the device
  - Response of an accelerometer embedded in the PZT stack
  - Temperature at both ends of the device
- We ran each test a second time, with the thruster rotated 180 degrees along the beam's axis.
  - By subtracting the two runs' thrusts, we removed non-reversing (i.e. spurious) thrusts.

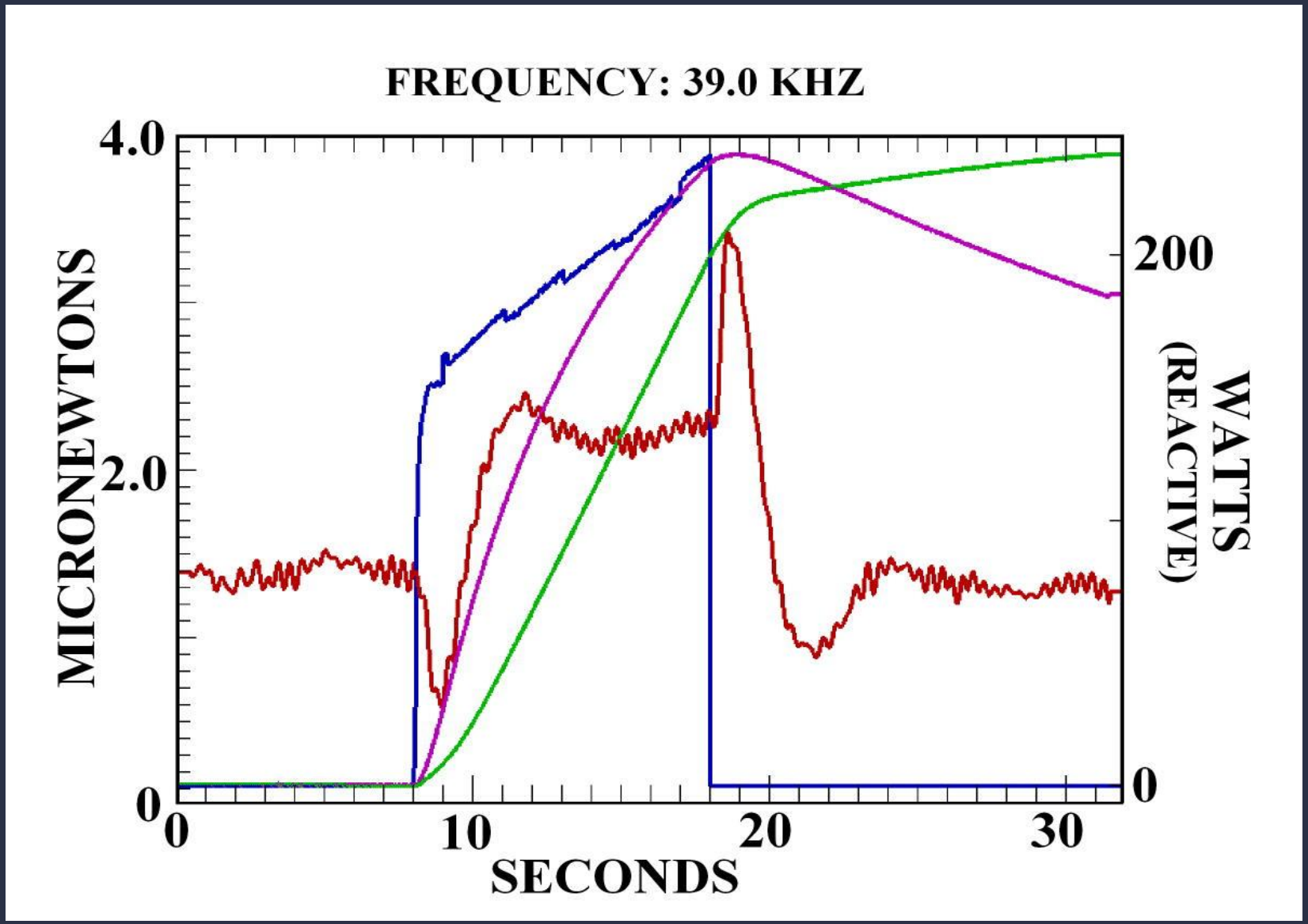
Device with 6 small bolts Results

- Initial runs at constant frequency were ten seconds long.
- On-resonance runs show a steady thrust.
- Transient signals appear at the start and end of each run.



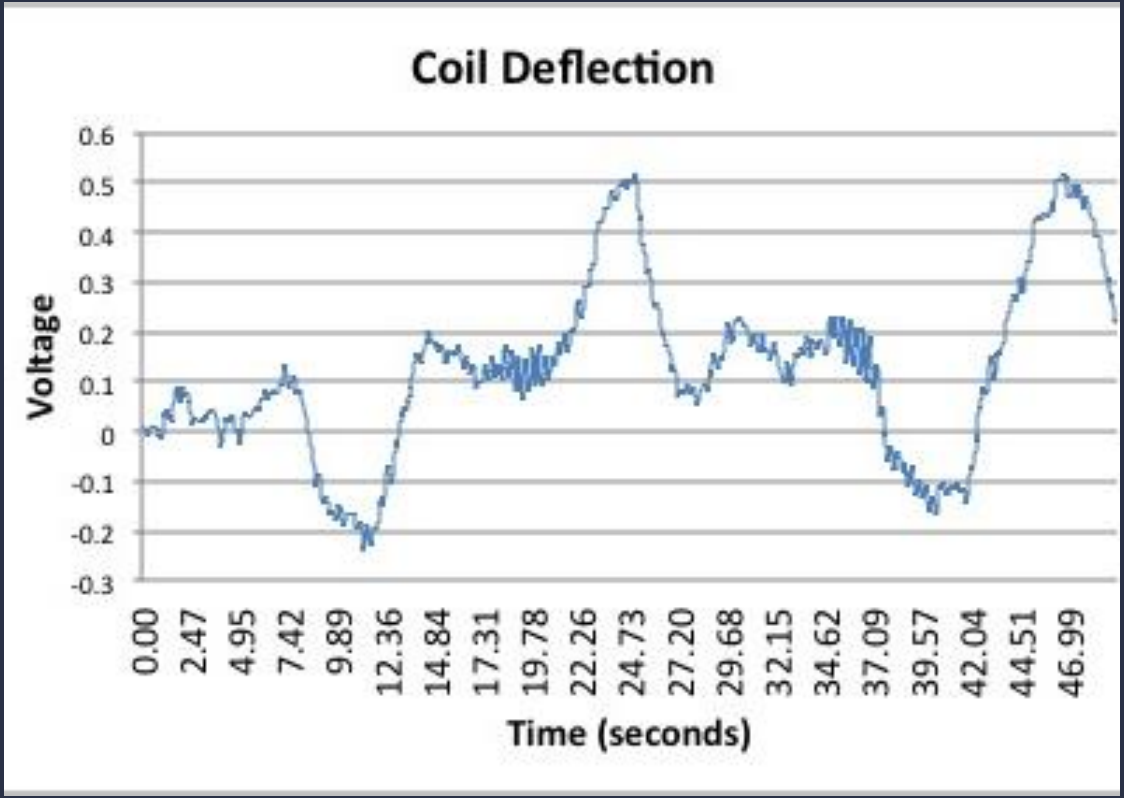


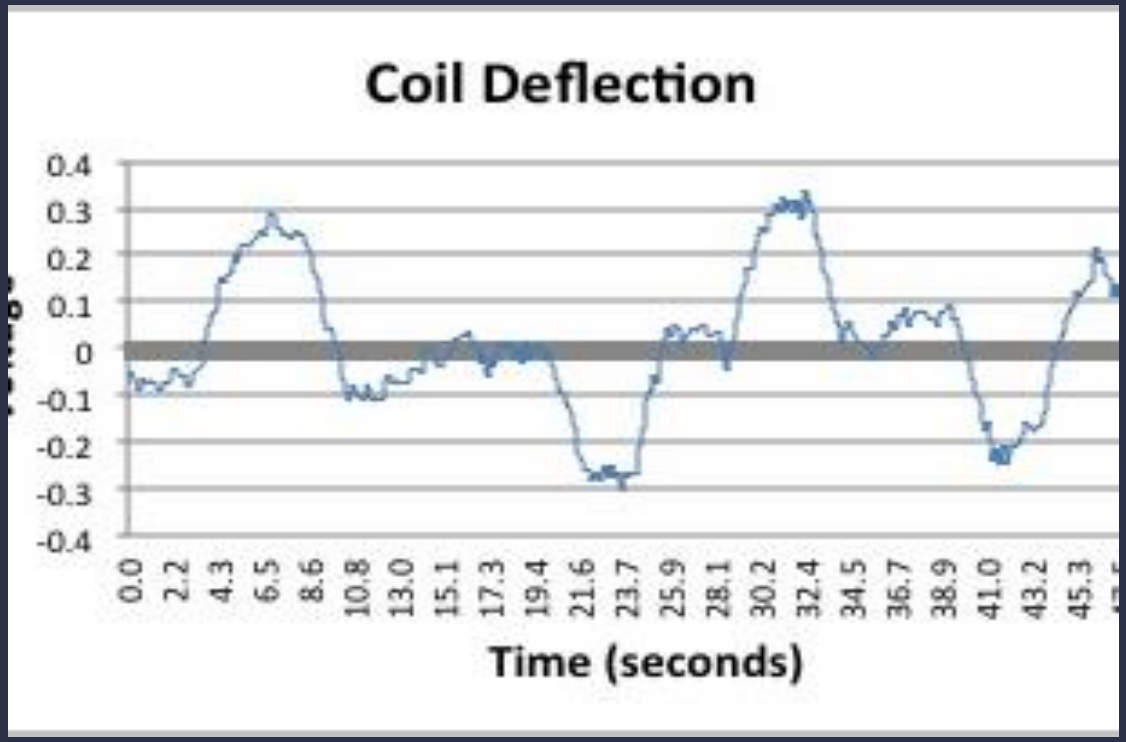
Power (dark blue), Accelerometer (light blue), and Thrust (red)

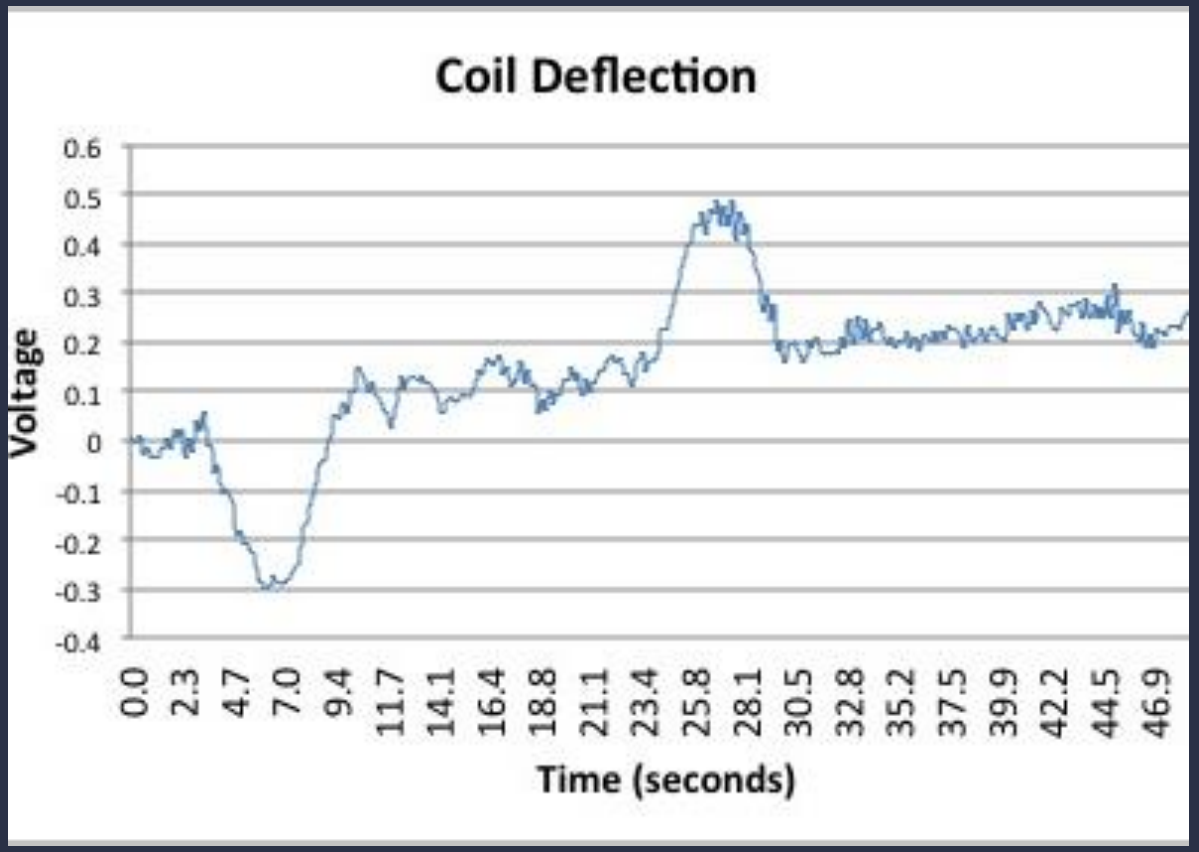


Power (dark blue), Thrust (red), Aluminum Cap Temperature (magenta, ~6 degree C rise), and Brass Cap Temperature (green, ~4 degree C rise)

Check to see if the Balance is “sticking”
Use calibration coils. Worst case scenario.




Coil Deflection
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0.0
2.2
4.3
6.5
8.6
10.8
13.0
15.1
17.3
19.4
21.6
23.7
25.9
28.1
30.2
32.4
34.5
36.7
38.9
41.0
43.2
45.3
Time (seconds)

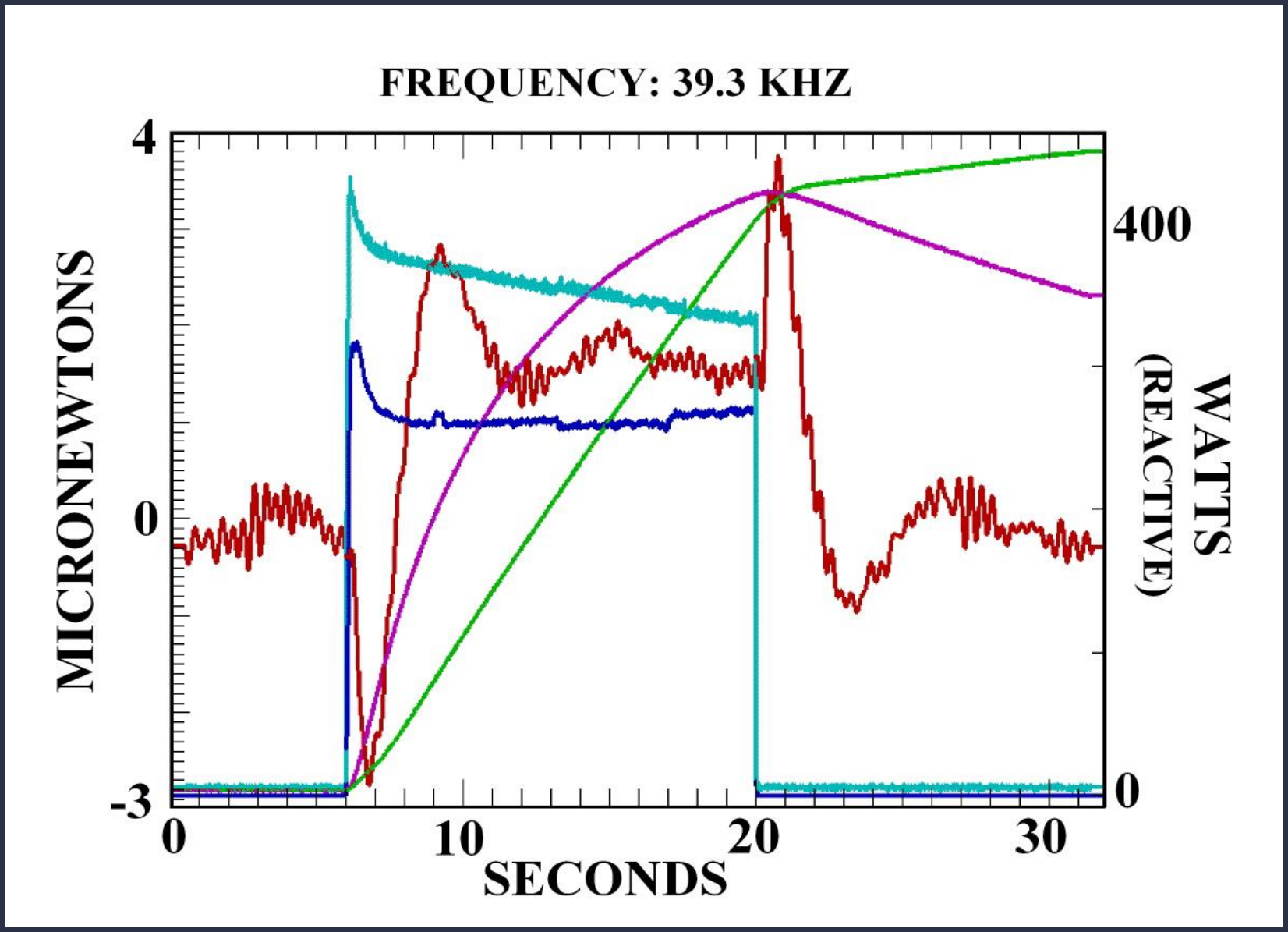


0.1V=100mV can at most give 0.6uN thrust.

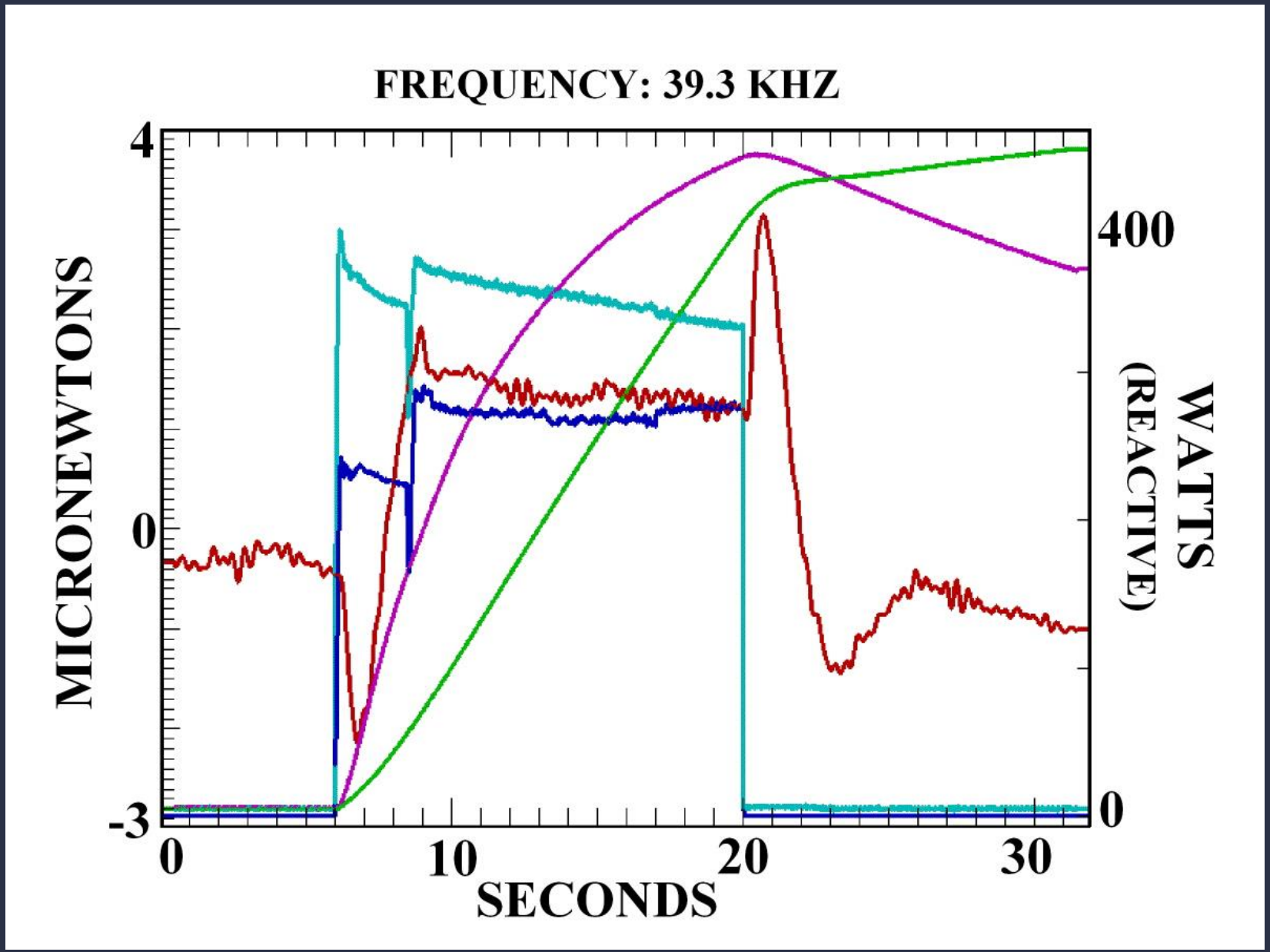
$$F = -0.0145 + 0.00614V$$

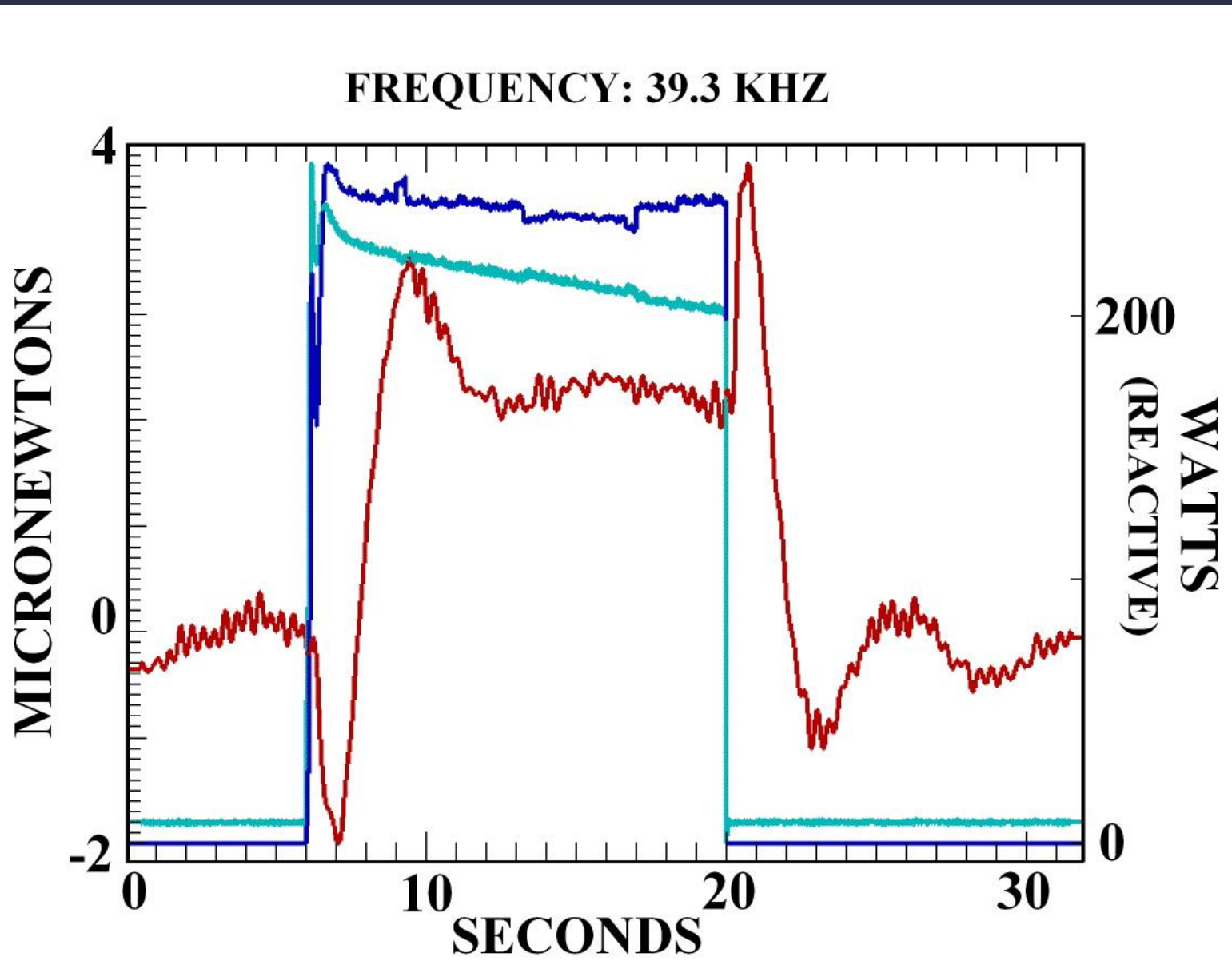
(For thrust in uN volts in mV.)

Recent 14 Second Constant Frequency Runs

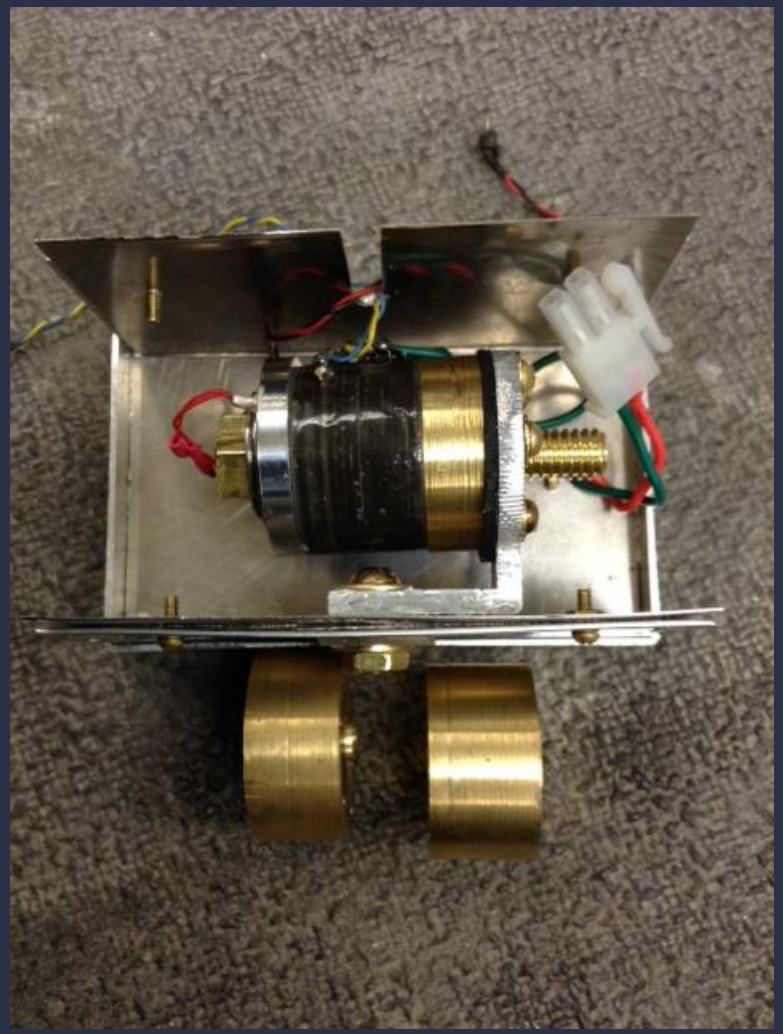


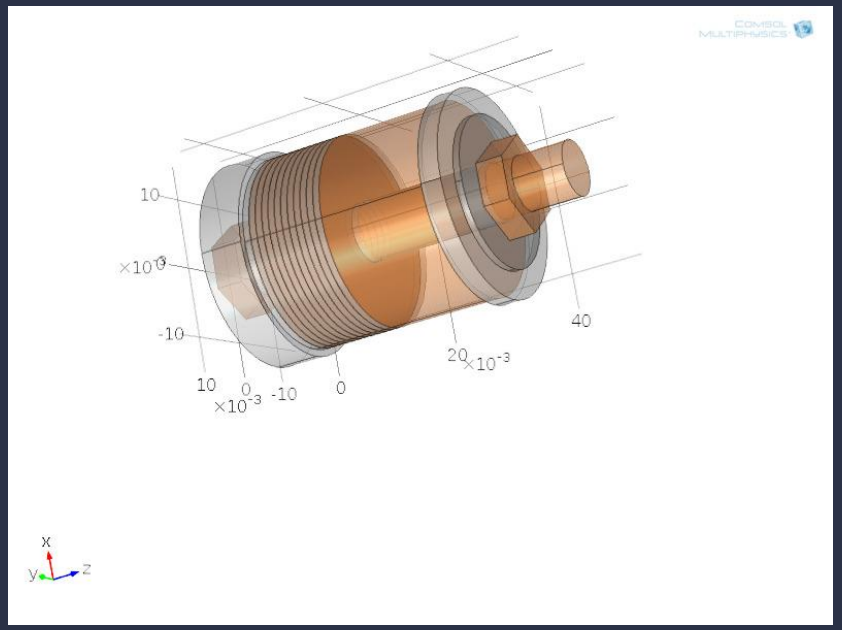
Power (dark blue), Accelerometer (light blue), Thrust (red), Aluminum Cap Temp (magenta), and Brass Cap Temp (green)


FREQUENCY: 39.3 KHZ
4
0
-3
MICRONEWTONS
400
0
WATTS
(REACTIVE)
0
10
20
30
SECONDS


FREQUENCY: 39.3 KHZ
4
0
-2
MICRONEWTONS
200
0
WATTS
(REACTIVE)
0
10
20
30
SECONDS

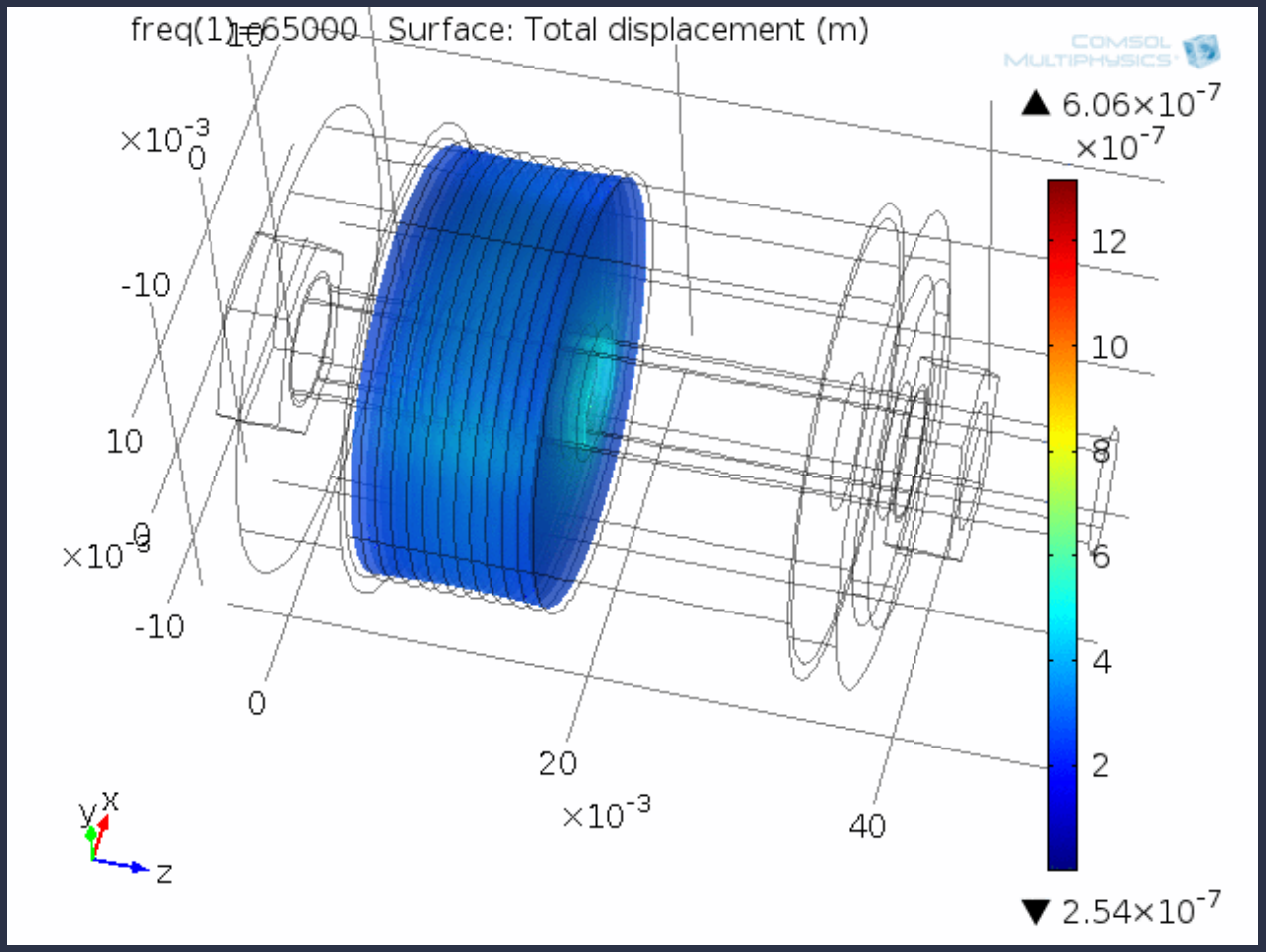
New Design Single Bolt



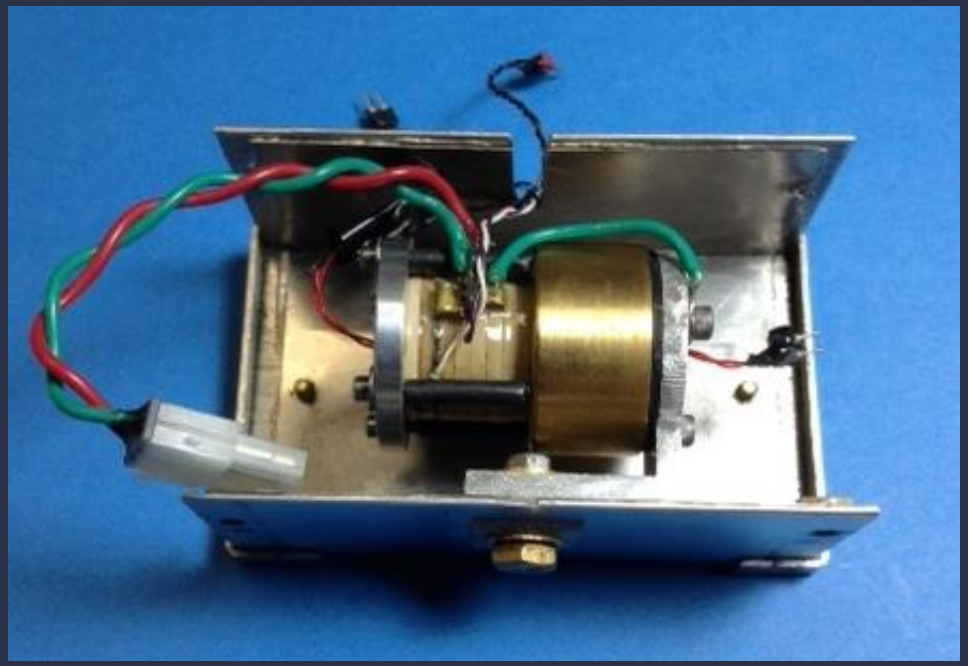


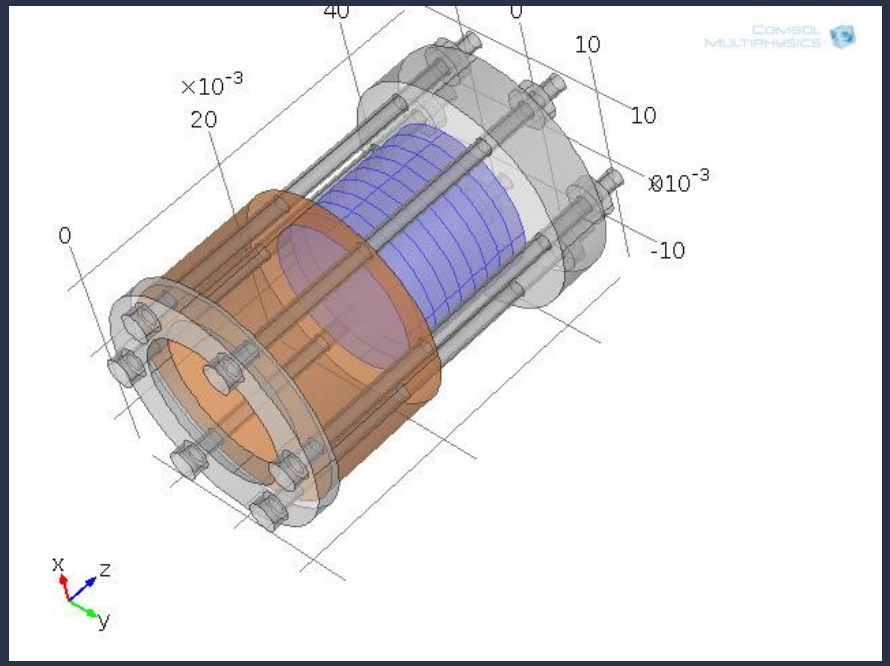
16 ,12 and 8 disk stack
Masses 5/8”, 1/2:” 3/8” brass.

COMSOL Animation of the PZT breathing mode

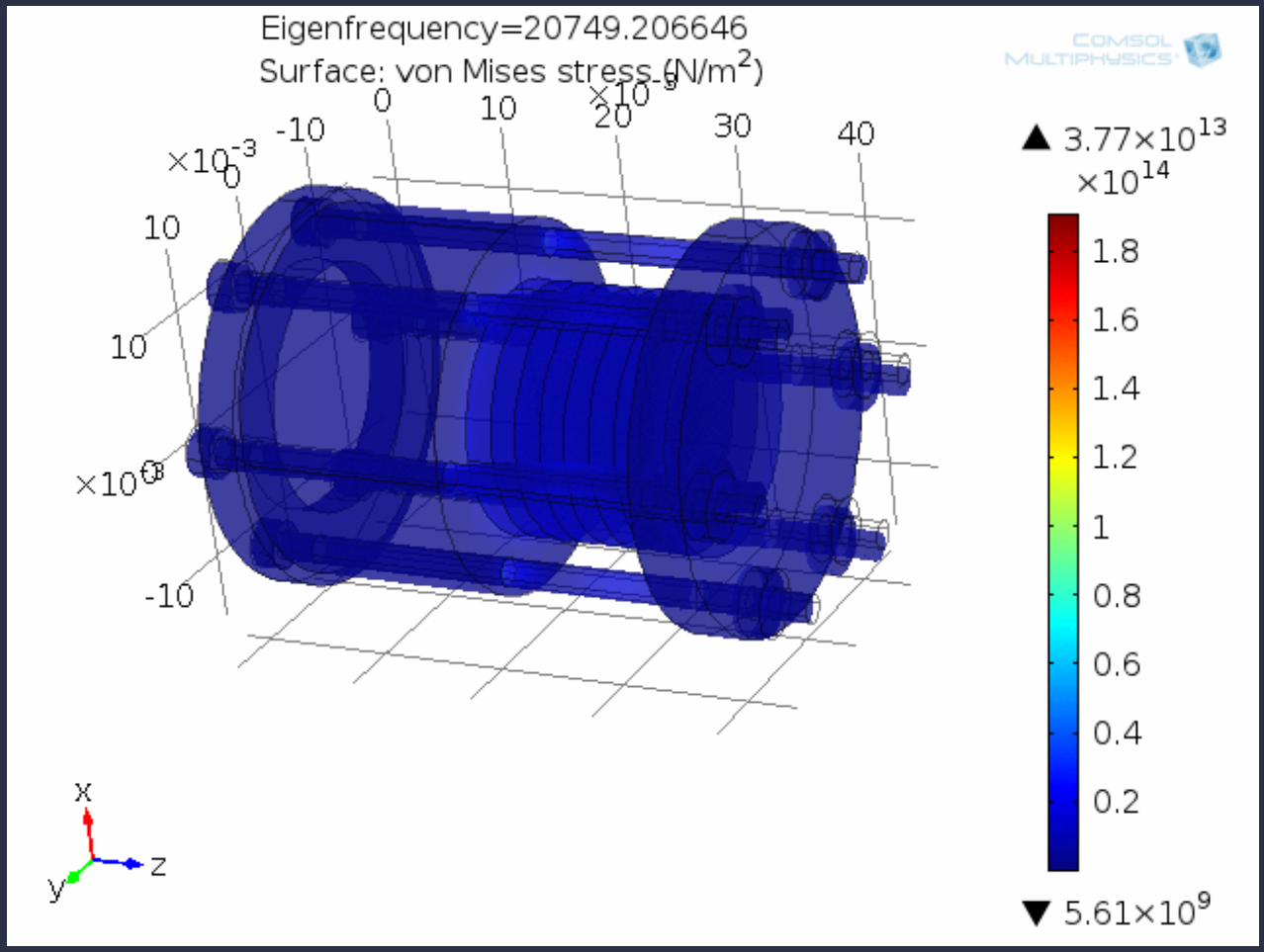


Device Using PMN





COMSOL PMN freq animation



Experimental Conclusions

- The experimental results suggest that Mach effect exists.
- The thrusts are closer than order of magnitude to those predicted.
- The experimental program aims to increase thrust to commercial levels for satellite station-keeping.

Theoretical Conclusions

Einstein believed in Mach's principle in 1918 and listed it on equal footing with his first 2 principles of relativity;

(1) The principle of relativity as expressed by general covariance
(2) The principle of equivalence
(3) Mach's principle (the first time this term entered the literature). . . . that the $g_{\mu\nu}$ are completely determined by the mass of bodies, more generally by $T_{\mu\nu}$.

In 1922, Einstein noted that others were satisfied to proceed without this [third] criterion and added,

"This contentedness will appear incomprehensible to a later generation however".

Heading of chapter 2 of Woodward's book and
quoted from "Subtle is the Lord; the Science and Life of Albert Einstein
" Abraham Pais, Oxford Univ Press pp287-288 (1982).

References:

[1] P. A. M. Dirac, “Classical theory of radiating electrons”, Proc. Roy. Soc. Lon. **A167**, 148 (1938).

[2] J. A. Wheeler and R. P. Feynman, “Interaction with the absorber as a mechanism for radiation”, Rev. Mod. Phys. **17**, 157 (1945).

[3] J. Cramer, “The transactional interpretation of quantum mechanics”, Rev. Mod. Phys. **58**, 647 (1986).

[4] K. Wanser “Center of mass acceleration of an isolated system…” Journ. of Space Exploration, 2, pp121-130 (2013).

[5] H. Fearn and K Wanser “ Experimental tests of the Mach Effect thruster’ J. of Space Exploration, to be published Dec 2014.

[6] Fearn, H. and Woodward, J. “Recent Results of an Investigation of Mach Effect Thrusters” American Institute of Aeronautics and Astronautics, JCP conference (2012). See also 20 years of Woodward’s work. [13-19]

[7] H. Fearn and J. F. Woodward, "Experimental Null test of the Mach effect thruster" Journ. of Space Exploration, an 2013. arXiv:1301.6178.

[8] H. Fearn, A. Zachar, J. F. Woodward and K. Wanser , AIAA Joint Propulsion Conference; Nuclear and Future flight Propulsion, "Theory of a Mach Effect Thruster", http://arc.aiaa.org/doi/abs/10.2514/6.2014-3821.

[9] F. Hoyle and J. V. Narlikar, "*Action at a distance in Physics and Cosmology*" W.H. Freeman and Company, San Francisco 1974.

[10] R. B. Partridge, Nature pp263-5 (1973)

[11] Nick Herbert "*Faster than Light; Superluminal loop holes in physics*" pp77-97 (A Plume book, Penguin Group, New York 1989).

[12] Ruth Kastner "*The Transactional Interpretation of Quantum Mechanics*", Cambridge University Press 2013.

… Woodward's older work….

Jim Woodward's work:

[13]. "Making the Universe Safe for Historians: Time Travel and the Laws of Physics",
Foundations of Physics Letters **6**, 1 – 39 (1995). (called the MUSH paper.)

[14]. "Killing Time", *Foundations of Physics Letters* **9,** 1 – 23 (1996).

[15]. "Twists of Fate: Can We Make Traversable Wormholes in Spacetime?", *Foundations of Physics Letters* **10**, 153 – 181 (1997).

[16]. "Are the Past and Future Really Out There?" *Annales de la Fondation Louis de Broglie* **28**, 549 – 568 (2003).

[17]. "Flux Capacitors and the Origin of Inertia". *Foundations of Physics* **34**, pp1475 – 1514 (2004). (Derivation of mathematics in the Appendix)

[18]. "Making Stargates: the Physics of Traversable Absurdly Benign Wormholes", *Physics Procedia* (proceedings of SPESIF 2011, 1 October 2011).

[19] "*Making Starships and Stargates*" Dec 2012 Springer Press.

Tests done.. Past and present….

DEAN DRIVE EFFECT:

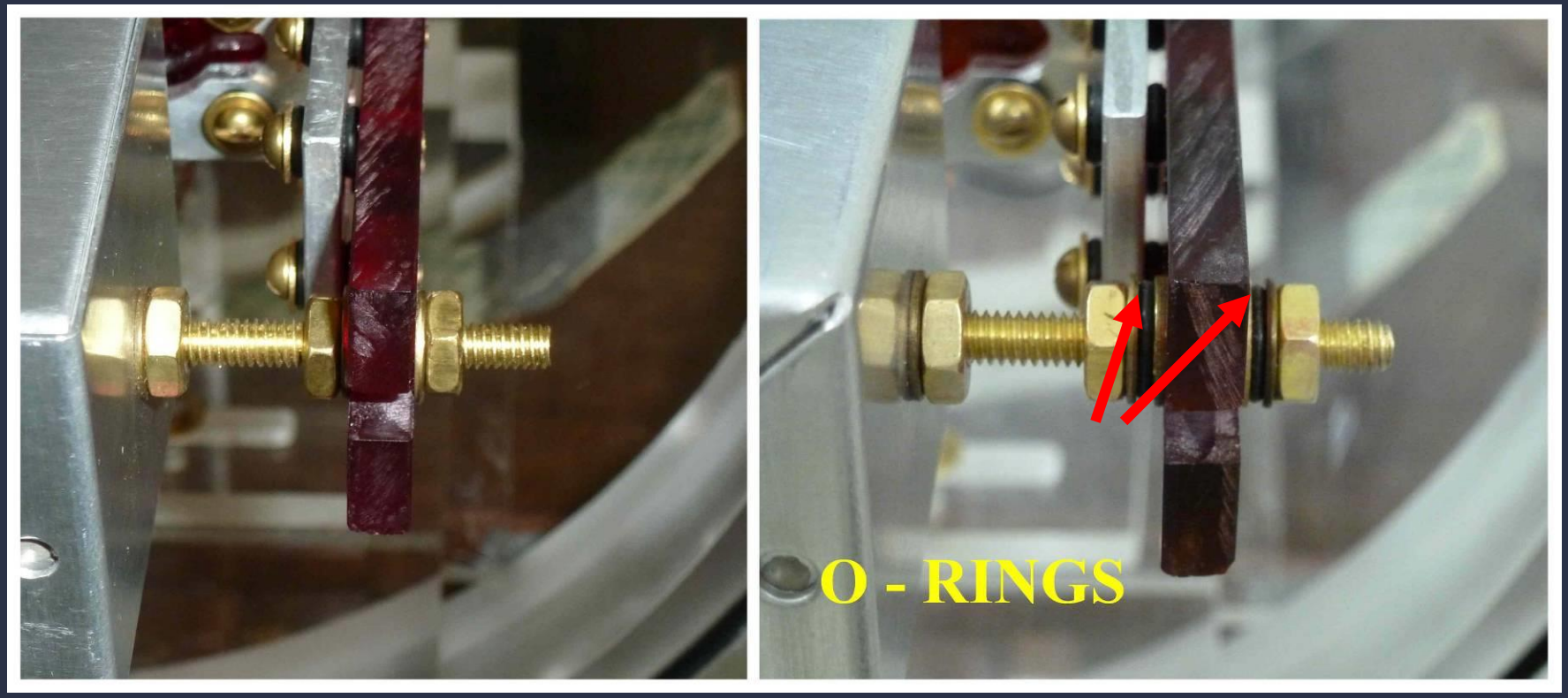
Earlier work showed no appreciable change in the thrust signals when all of the vibrations damping was removed, indicating that the thrust signals are not attributable to a Dean drive effect.
That conclusion is further supported by the response of the accelerometers fixed to the central balance beam support column and the collection of data for full vibration isolation, and when part of the isolation measures were removed.

Vibration Isolation:

Mechanical systems with vibration can often produce curious effects. They usually arise from parts of the system where both static and dynamical friction operate to produce motion in some direction. In this system, the vibration produced during the operation of the devices might act on the bearings that support the balance beam, and that vibration might cause the beam to move.

Several tests for the effects of vibration were conducted. The results were all negative, the following test being typical.

Variation of the vibration isolation:



The two configurations of the mounting bolt attachment to the (dark red) plastic fork on the end of the balance beam. On the right the rubber O – rings normally present to attenuate vibration are indicated by the red arrows. On the left, the O – rings have been removed. The O – rings reduce the vibration reaching the center support column of the balance by 25%. But this had no effect on the thrust detected with the balance.

Typical temperatures during a 14 second run.